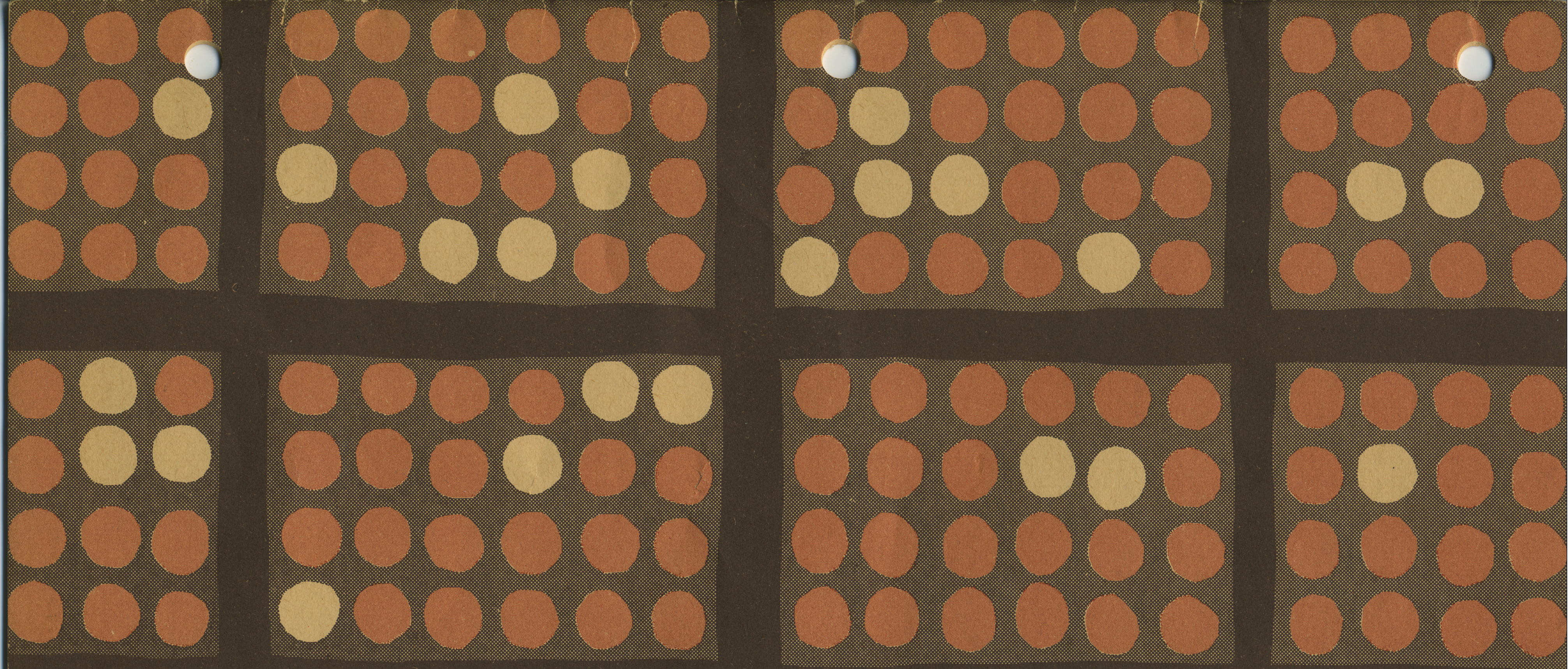
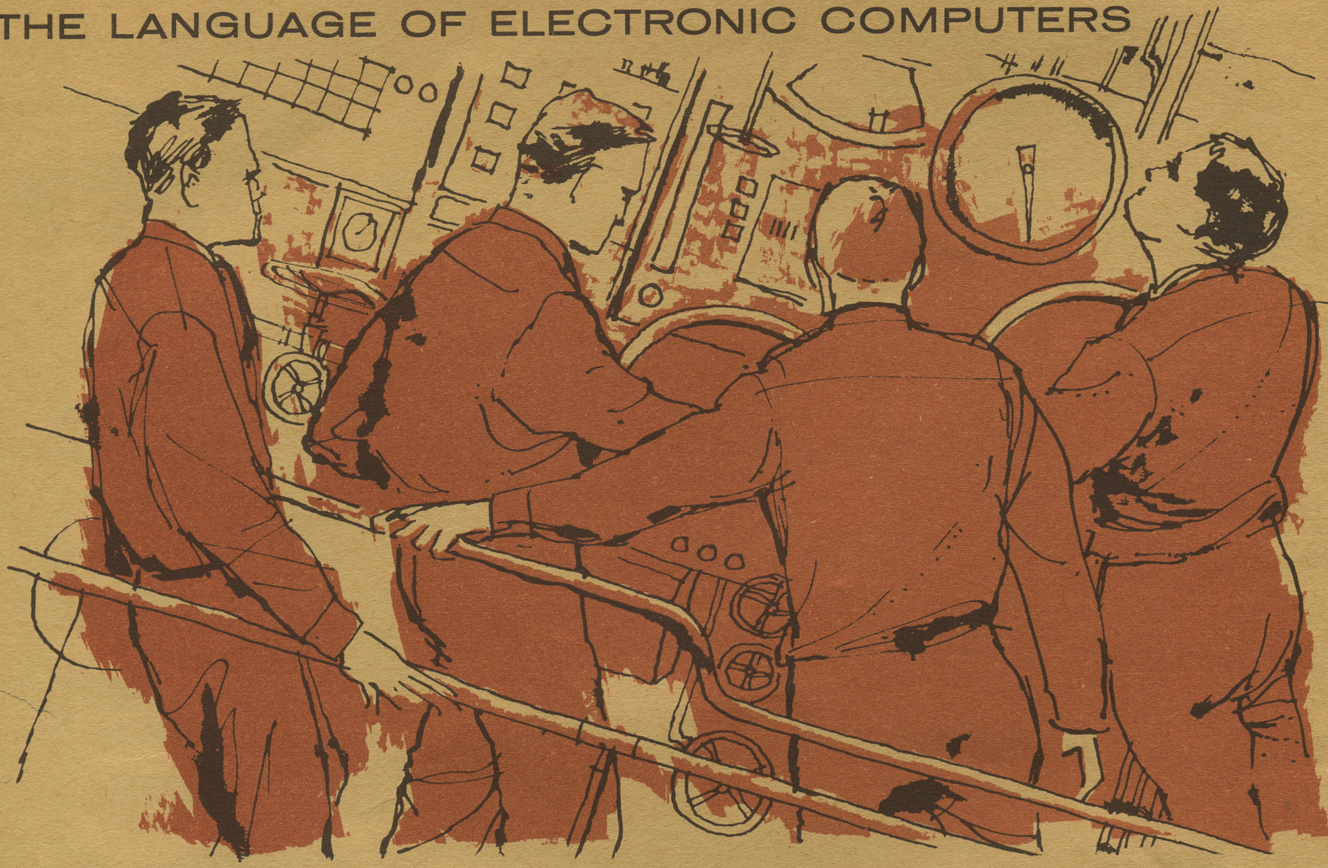


YES, NO - ONE, ZERO

YES, NO – ONE, ZERO

THE LANGUAGE OF ELECTRONIC COMPUTERS



"Take her down!"

The blast of the dive horn echoes through the boat. Submerge! The deck officer jumps down the hatch from the conning tower. Gripping the steel ladder with one hand, he slams the hatch shut and secures it. Everyone is on station. Dials show that the sea cocks are open and water is flooding into the tanks. The deck tips forward. The men brace themselves for the dive. A new man tries to adjust himself to the feel of the sub. He looks ill. "Easy, lad," whispers an old hand. "You'll get the hang of it." The boat is running silently now at ten knots. An eerie red glow lights up tense faces, alert for the next action.

Is the boat under the South Pacific? The Arctic ice pack? Actually, it's on dry land, at a navy school that trains men for submarine duty. The "submarine," although big enough to hold a dozen men, is just one part of a tremendous training device called a "simulator," which duplicates the sounds of a submarine, the meter readings, and even the changing tilt of the deck. These make-believe conditions are changed and controlled by an electronic computer in which coded data have been stored. This electronic control device is one of the many that are sometimes called "giant brains," "thinking machines," or "robots that think."

These names are misleading. No device can really *think* in the usual sense, but these computers do important, exciting things. They spot high-altitude weather conditions and warn us of storms, hurricanes, and tornadoes faster and more accurately than any weather-forecasting device ever used. They predict the paths of earth satellites, or the results of presidential elections.

Computers do mathematical problems in hours that would take more than a man's lifetime to solve with paper and pencil. They help major industry per-

form its manufacturing operations better, for with their aid, skilled men can control complex combinations of machines.

What are these devices? In what sense do they think? Will they replace the human brain?

This booklet answers some questions about computers, and about other electronic devices controlled by computers. As a start, here are two statements that may help you appreciate computer "thinking machines" and the "thinking machine" you are using now—your own brain.

One scientist has said that if we *could* build a machine to duplicate the human brain, we would need a skyscraper to house it, the power of Niagara Falls to run it, and all the waters of Niagara to cool it. A mathematician adds that computers are really stupid, for they can only follow the simplest directions from their human masters. These two statements show clearly that the human brain is not obsolete.

But if computers have no intelligence, how can they perform their complex tasks? Let's examine some of the basic principles which make computers possible.

Computers are devices capable of solving complex mathematical problems. They are different from earlier calculators which do only one kind of mathematical operation at a time. We use two kinds of computers today: *analogue* and *digital*. Both determine quantities. The analogue determines quantity by measurement—how much. The digital determines quantity by counting—how many. The example at the top of the next column may help clarify the difference.

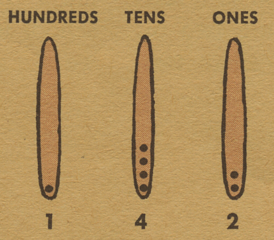
The applause meters often used on TV shows are analogue computers. They determine the winners of contests, for example, by measuring "how much" applause each participant receives. The volume of sound created by clapping hands is converted to an electric voltage which moves a needle on a numbered dial. The physical movement of the needle on the dial corresponds to the volume of applause, which can be roughly translated into the number of people applauding. Thus, the volume of sound is *analogous* to the quantity we want to measure. Slide rules, thermometers, and weight scales are other examples of analogue computers.

Of course, we can determine the winner of a talent contest in another way. We can *count* the number of people applauding. This is *digital* computing. Our story is about electric devices that determine quantities in this way—by counting.

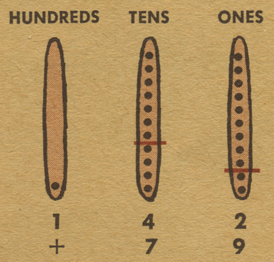
The word "digital" refers to counting and it also refers to fingers. Do you see a connection? Most children learn to count on their fingers. Our ten fingers are the simplest digital computer. Scientists, tracing the history of computation, say that man learned to count by tens because he had ten fingers. Let's trace the development of number systems to help us understand some basic principles of computers.

Thousands of years ago, the Egyptians used a number system based on ten. They had a way of calculating without written symbols, using pebbles set out in grooves in the sand. Each pebble in the right-hand groove represented one; each in the next groove, ten; each in the third, one hundred.

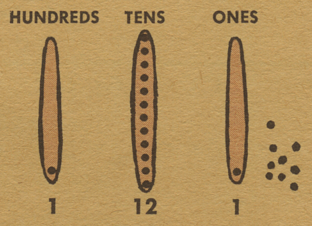
HERE'S HOW YOU WOULD ADD 79 TO 142 WITH THE EGYPTIANS' SAND COMPUTER



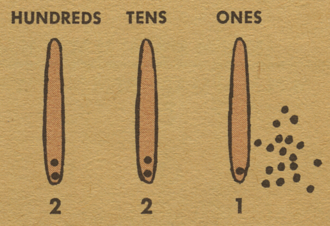
1 To add 79 to 142, first place pebbles to show 142 as above: 1 hundred, 4 tens, 2 ones.



2 Add pebbles to show 79: 7 tens and 9 ones. Now ones and tens column have 11 pebbles each.



3 Exchange 10 pebbles in ones column for one pebble to be placed in tens column. Ones column now has one pebble and tens column has 12.



4 Exchange 10 pebbles in tens column for one to be placed in hundreds column. Pebbles now give correct answer of 221.

NOW TRY ADDING 254 AND 168 BY THIS METHOD

The Egyptian system was also the basis for the abacus. The abacus is a simple calculating device using rows of beads strung on wires and set in a frame. Calculations are made by moving the correct number of beads to represent the quantities involved. In a way, the colored beads on a baby's play pen are like an abacus. If you take your father's shirts to a Chinese laundry, perhaps you will see an abacus in use. This ancient Chinese invention is still extremely useful. On a recent TV show, a young girl solved problems with an abacus more quickly than a man using an electric desk calculator. Though the abacus is simple in construction, great skill and practice are needed to perform quick mathematical operations with it. Much of the work is done by mental arithmetic.

The Egyptians and Chinese contributed greatly to the science of counting, but progress in the art of calculation was limited until men learned to write number information in simple, uniform fashion. This achievement, like the invention of the wheel or the loom, was one of the big steps forward in human history.

The Hindus of ancient India developed the system of numbers we use—the decimal system. By this system, any number can be represented by a combination of ten symbols: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. These symbols in different places in a number can represent ones, tens, hundreds, thousands, and so on. In the number 3333, for example, the symbol 3 has different values depending on its placement. The 3 on the extreme left represents three thousand; the 3 on the extreme right represents three units; the symbols in between represent hundreds and tens.

A very important part of the decimal system is the zero. It doesn't look very nice alone at the top of a test paper, but it does look handsome if there are two of them preceded by the symbol 1. On an excellent test paper, where you receive 100, the zeros tell that the symbol 1 stands for one hundred points. The zeros place the symbol 1 in the position where it represents one hundred. The zero can be described, therefore, as a "place holder."

The next time you are in a car, watch the mileage indicator. It's an example of the decimal system in action. Notice that, if you start at 000, as the number in the units column moves up past 9 it changes to 0. Simultaneously, the next column changes to 1, indicating ten miles of travel.

The mathematics history books listed at the end of this booklet describe number systems that men developed in different societies. Some are rather awkward and almost useless to us. The Roman number system is one example. We use Roman numerals on fancy watches, on cornerstones of buildings, in preparing outlines for school themes, perhaps to number book chapters. The Roman symbols are I for one, V for five, X for ten, L for fifty, C for one hundred, D for five hundred, and M for one thousand. To record 1,156, you would write the symbols for 1,000 plus 100 plus 50 plus 5 plus 1: MCLVI. Can you write the year of your birth in Roman numerals?

The Roman system is awkward, but that's not all. As numbers get larger, you need more symbols. This means you must remember many symbols. The illustration below shows you how cumbersome it is to multiply, using the Roman system.

Pretty awful, isn't it? It is easy to see why the Roman number system is practically obsolete.

So far, our review of mathematics history has covered things you learned in elementary school. Did you know that the simple arithmetic you learned in grade school was once a university subject? Does that mean we are smarter than ancient people? No, not in native

PROBLEM: MULTIPLY 133 BY 126

		C		XXX		III
		C		XX	V	I
		C		XXX		III
	D		LLL		VVV	
M		CCC		XXX		
M		CCC		XXX		
MMMMMMMMMMMMM		CCC				
MMMMMMMMMMMMMMM	D	CCCCCCCCCC	LLL	XXXXXXXXX	VVV	III
			LLLLL		V	
		CCCCCCCCCCCC	L			
	DDD	CC				
MMMMMMMMMMMMMMMM	D					

MMMMMMMMMMMMMMMMDCCLVIII = 16,758

intelligence. But we are more advanced because we apply to today's problems ideas men recorded centuries ago. The decimal system we use is good. It will remain useful for many hundreds of years. But the tremendous advances of the past fifty years in science and technology made it necessary to find other ways of calculating. Neither the decimal system, based on 10, nor other number systems based on 12, 20, or 60, could meet the computational needs of modern society.

Today's mathematician has to deal with thousands of calculations in solving problems of rockets and missiles. The rapidly changing world of business and industry needs high-speed answers to complex problems. Progress was limited by outdated computational methods until research produced an answer. The answer was a system of numbers which made modern electronic computers possible—the *binary* system.

The binary number system is based on two symbols only: 1 and 0. The great mathematician, von Leibnitz (1646-1716), is credited with the discovery of this system, although it appears to have been used in China four thousand years ago. By giving the symbols different *place values,* all numbers can be represented through combinations of the two symbols, 1 and 0. In the decimal system, as a digit is shifted one place to the left, its value is multiplied by *ten.*

THIS NUMBER→	4	4	4	4
	THOUSANDS	HUNDREDS	TENS	ONES
	4x1000	4x100	4x10	4x1

MEANS→ 4,000 + 400 + 40 + 4 = 4,444

In the binary system, as the symbol is shifted one place to the left, its value is multiplied by *two.*

THIS NUMBER→	1	1	1	1
	EIGHTS	FOURS	TWOS	ONES
	1x8	1x4	1x2	1x1

MEANS→ 8 + 4 + 2 + 1 = 15

As you can see in the chart, the symbol 1 can be used to represent one, two, four, or eight, depending on its position or place.

Let's use the binary system to do some actual counting. You may have a little trouble at first because you have used the decimal system all your life, but you will soon see how it works.

The first two decimal numbers are represented by the symbols 0 and 1. What's next? Two. But we can't use the symbol 2, because no such binary symbol exists. We can use only the symbols 1 and 0 and the idea of place value. Number two, therefore, is shown as 1 0. The 0 on the right indicates an empty place. The symbol 1, on the left, represents the quantity *two* because of its placement. The next number in counting is *three,* represented by 1 1. Here the symbol 1 on the left represents two, the symbol 1 on the right *one.* Two plus one equals three, and so on down the chart. Notice that, as the symbol 1 shifts one place to the left, its value is multiplied by two.

BINARY SYSTEM

2^4	2^3	2^2	2^1	2^0	
SIXTEENS	EIGHTS	FOURS	TWOS	ONES	
2x2x2x2	2x2x2	2x2	2	1	
16	8	4	2	1	DECIMAL EQUIVALENT
				1	1
			1	0	2
			1	1	3
		1	0	0	4
		1	0	1	5
		1	1	0	6
		1	1	1	7
	1	0	0	0	8
	1	0	0	1	9
	1	0	1	0	10
	1	0	1	1	11
	1	1	0	0	12
	1	1	0	1	13
	1	1	1	0	14
	1	1	1	1	15
1	0	0	0	0	16
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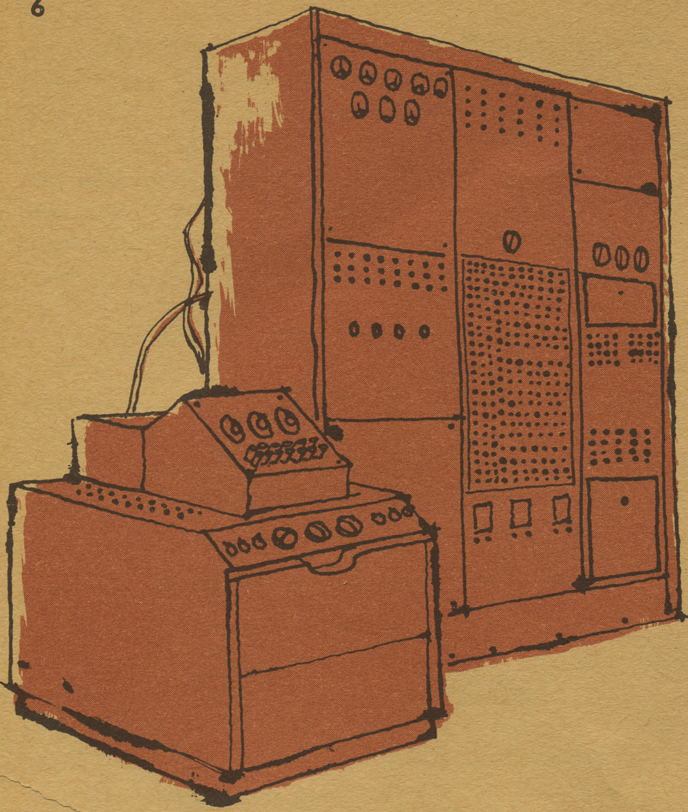
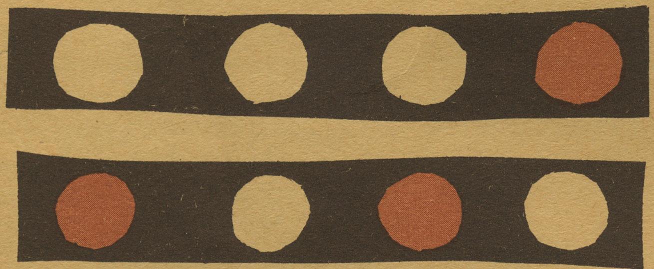
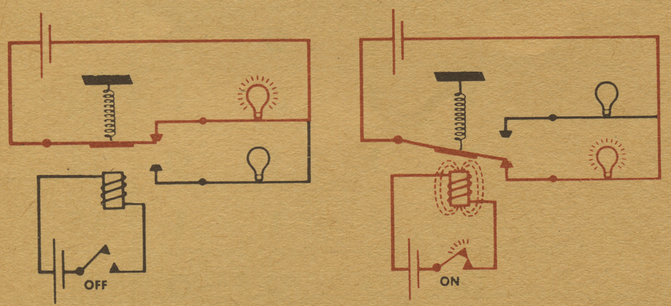
1	0	0	1	1	19
1	0	1	0	0	20

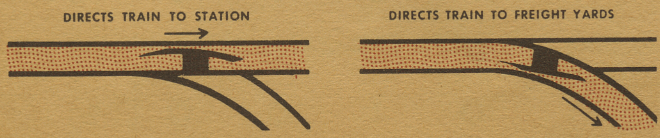




ELECTROMAGNETIC RELAY DIAGRAM



RAILROAD SWITCH



Now try writing some binary numbers between one and twenty without consulting the chart. This will help you change your thinking to binaries. You can check yourself by using the page numbers of this booklet. They are numbered in both the binary and the decimal systems. As you write binaries, you may find them as awkward as Roman numerals. The next section will show you, however, that, while poorly suited for "hand" work, they *do* have real value.

SUMMARY: *The binary number system gives us a way to represent* any *number; by using two symbols, 1 and 0, and the idea of place value.*

How does the binary system provide the key to modern electronic computers?

A brief review of electric circuits is essential before this question can be answered. In any electric circuit, there are only two conditions: one when the current is *on,* the other when the current is *off.*

Do you see the connection between the *two* symbols of the binary system and the *two* conditions in electric circuits? Suppose that you have a row of four light bulbs. These lights may be turned on or off by switches. If a light is on, the current is flowing. If the light is off, the current is not flowing.

Let's use this same row of lights to represent numbers in the binary system. Let us say that if a light is on, it stands for the symbol 1; if the light is off, it stands for the symbol 0. This gives us a way to translate any four-place number information into electrical conditions, as shown here by bulbs that are either on or off. Look at the upper panel of lights representing the number fourteen or 1 1 1 0 in binaries.

What number does the lower panel of lights at left represent? Check the page numbers for the answer.

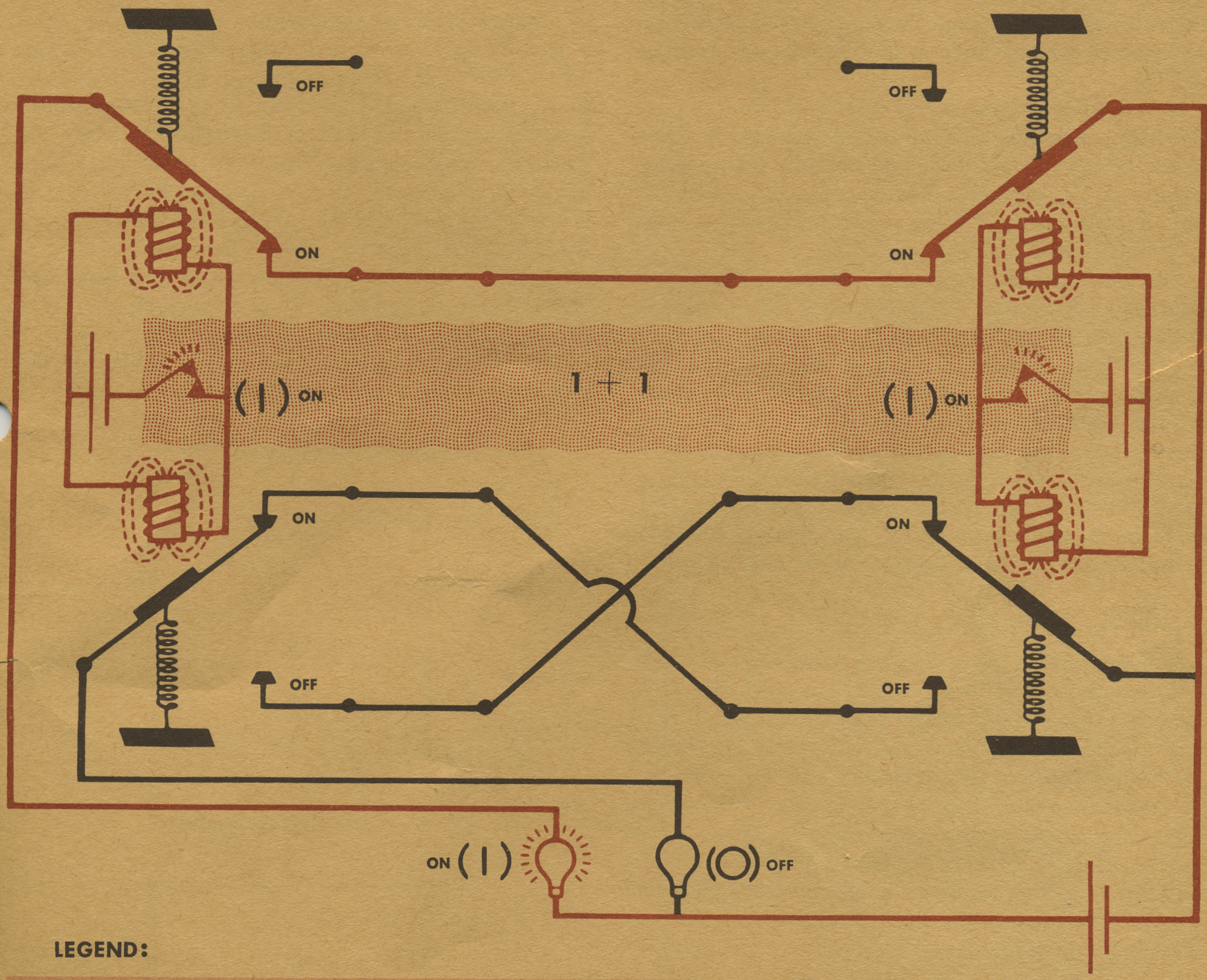
The simplest device for turning electric current on or off is a switch. You use a switch every time you ring a doorbell or turn on a light. To represent the number 14, we used four separate switches. But computers must do more than show a single number. They must *use* two or more numbers. They must combine numbers to add and subtract. They must do a series of additions to multiply; they must do a series of subtractions to divide. Therefore, there must be some means of connecting one circuit to the other so that a number in one circuit can be combined with another number in another circuit. We need a means which allows the electrical condition of one circuit to affect another.

The *relay* is such a device. It's like a railroad switch in that it can select one of two paths. It can direct an electric current into one of two circuits. Relays, basically, are switches operated by electromagnets. As such, they can be held in either of two positions: magnetized or non-magnetized. This makes it possible to "hold" or "store" coded information. Whenever a device can store information, it has what is called a "memory."

Modern computers don't use relays. They use electrical systems that are infinitely more complex, but which operate on the relay principle. Electronic tubes similar to those in your TV or radio set are used because they work at the speed of light. This is a great advantage. At this speed, a rocket could go around the earth 7½ times in one second. You can see that a great variety of electrical conditions, or numbers, can be recorded and acted upon at a fantastic rate.

Although computers have developed from switch and relay to electronic tube devices, the binary number system remains the basis for their design and construction. With binaries it is possible to represent and process any combination of numbers, letters, or both.

HERE'S A SIMPLE ELECTRO-MECHANICAL COMPUTER THAT CAN COMPUTE THE BINARY ADDITION TABLE. IT IS SHOWN COMPUTING 1 + 1 = 10.



LEGEND:

- BATTERY
- SWITCH
- ELECTROMAGNET
- OFF (O)
- ON (1)
- SPRING
- RELAY ARMATURE OR TWO POSITION SWITCH
- ELECTRICAL CONNECTION
- NO ELECTRICAL CONNECTION

BINARY ADDITION TABLE

0 + 0 = 0

0 + 1 = 1

1 + 0 = 1

1 + 1 = 10

No single booklet can do more than hint at the basic principles of computer construction and operation. Several excellent books listed on page 1 1 1 1 give you sources of information for constructing a simple computer.

At school science fairs, students win prizes each year for their relatively simple computers, logic machines, and robots. Most of these are based on combinations of basic electric circuits and the binary number system. Try working out some of the circuits. Some ideas of your own may be a major contribution in this growing field. Remember, amateurs played an important part in our own time in the development of radio and TV.

If you build a computer of your own, you will see that it operates only on information you give it. Computers are not "brains." They do no more than you tell them to do. If you feed yours incorrect information, it will give you incorrect answers. In addition, you must tell it exactly what to do, step by step.

This raises another important point about computers: It usually takes much longer to tell a computer how to do a job the first time than it would take to do the job "by hand." However, once a set of instructions or *program* has been prepared, it is relatively simple for the machine to *repeat* the calculation with new data. Where long and complex calculations must be run repeatedly, the computer offers tremendous savings. Industrial operations require thousands of routine calculations. Monthly payrolls are one example; for each person employed, the same calculation must be made:

HOURS WORKED × **PAY RATE PER HOUR** − **DEDUCTIONS** = **SALARY**

Computers are of great value for this kind of work.

Computers are not brains. They can only solve problems that theoretically could be solved by a sharp mind and a sharp pencil. They can only make calculations and simple decisions for which they have been prepared or programmed by men. A computer's decisions are limited to simple yes-no, on-off, go-stop types. It has but two choices. Extremely complex problems must be reduced to a long series of simple, interrelated steps. Think of the factors you must resolve before you can answer this question:

SHALL I GO TO COLLEGE?	☐ yes	☐ no

The men who organize and re-state problems in terms a computer can accept are called *programmers*. Programmers are really language experts. The languages they use aren't all spoken languages like Spanish, French, or English. Some are universal languages, understood by scientists and technical people the world over. These are mathematics and the language of logic. Maybe you don't think of mathematics as a language, but it is. It is one means used by men of science and business to communicate with each other.

A programmer must know these four languages:

(1) His native tongue
(2) The language of the flow or block diagram
(3) The language of logic
(4) The language of the specific computer with which he is working. This includes the codes of letters, binary digits, or combinations of them.

How do you get to be a programmer? No one can give you a good answer to this question. The profession is so new, and is changing so fast, that the most practical approach is to look at what programmers do. Primarily, they analyze problems to reduce them into the small, simple parts a computer can handle.

One technique used by programmers is to prepare *flow* or *block diagrams*. These diagrams arrange the steps of a process in order and show how the steps are related to one another. They aid memory and force precise thinking. They show how to solve a problem.

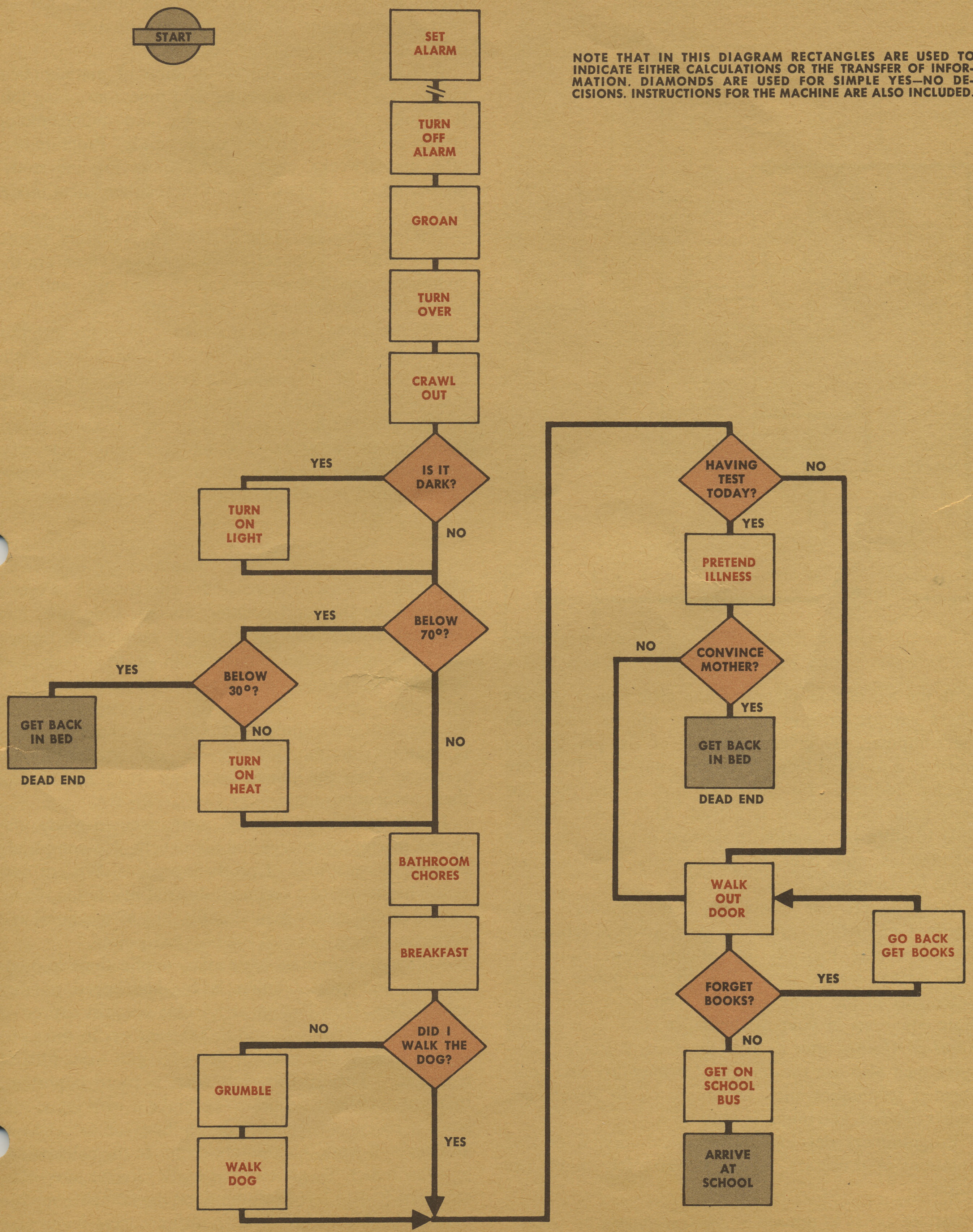
For instance: How do you get to school in the morning? A flow diagram of this problem might be:

This may be enough for you, but it's not detailed enough for a computer. Your mind makes connections readily. It fills in gaps from past experience. Computers need a simple, step-by-step plan with complete instructions.

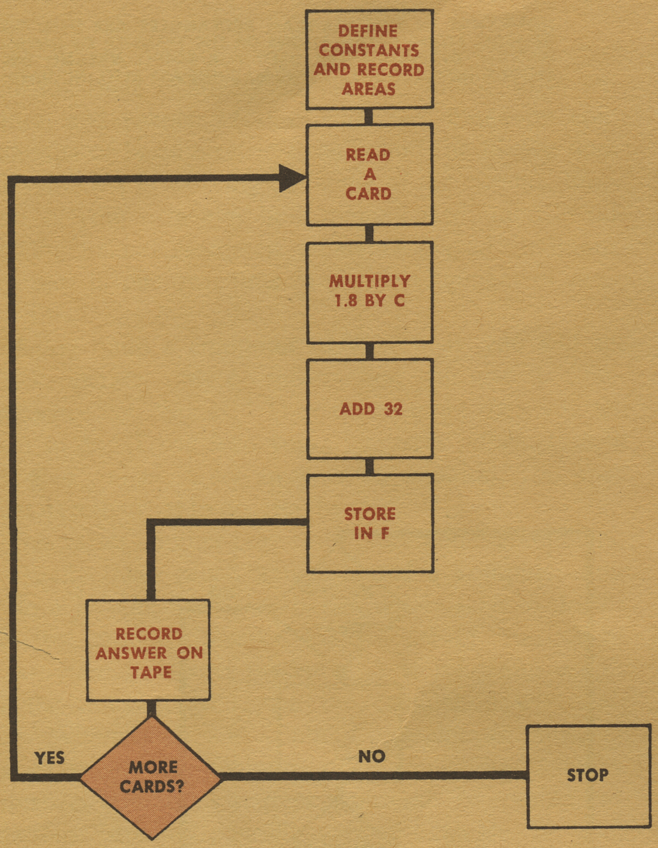
Programmers might attack the problem in this way:

PROGRAM: HOW TO GET TO SCHOOL IN THE MORNING

NOTE THAT IN THIS DIAGRAM RECTANGLES ARE USED TO INDICATE EITHER CALCULATIONS OR THE TRANSFER OF INFORMATION. DIAMONDS ARE USED FOR SIMPLE YES—NO DECISIONS. INSTRUCTIONS FOR THE MACHINE ARE ALSO INCLUDED.



The familiar mathematical problem of changing centigrade temperature readings to Fahrenheit ($F = 1.8\,C + 32$) is diagrammed like this:



With the aid of flow diagrams, the programmer decides where various parts of his problem will be worked in the computer. He gives each part of the problem an *address,* a physical location in the computer. There are specific addresses for data and instructions that are used until the problem is solved. This makes it possible to store information in desired patterns, to make calculations, and, later, to make partial solutions part of the final solution.

Programmers use many other mathematical techniques. One method, *symbolic logic,* involves representing statements logically by mathematical equations. This system makes it possible to manipulate logical statements in the same way that you work with algebraic equations in your mathematics class. It is named *Boolean Algebra* after its inventor, George Boole. Computer men also use the *theory of probability* and complicated techniques such as *Monte Carlo simulation, matrix algebra,* and *multiple regression.*

Programmers develop mathematical models of real situations or processes. Here's an extremely simple example:

COST OF APPLES IN DOLLARS = \$0.08 × NUMBER OF APPLES

This equation is a "model" of an actual buying situation. It predicts the cost of any number of apples. No apples need ever be purchased in order to get answers. All aspects of this limited situation can be explored without spending a cent.

In actual practice, the preparation of mathematical models is a complex, exacting, and time-consuming job. It requires a thorough knowledge and understanding of the problem or process under study. Programmers often spend weeks, even months, observing and studying before they begin to design the mathematical model for which a final program will be prepared.

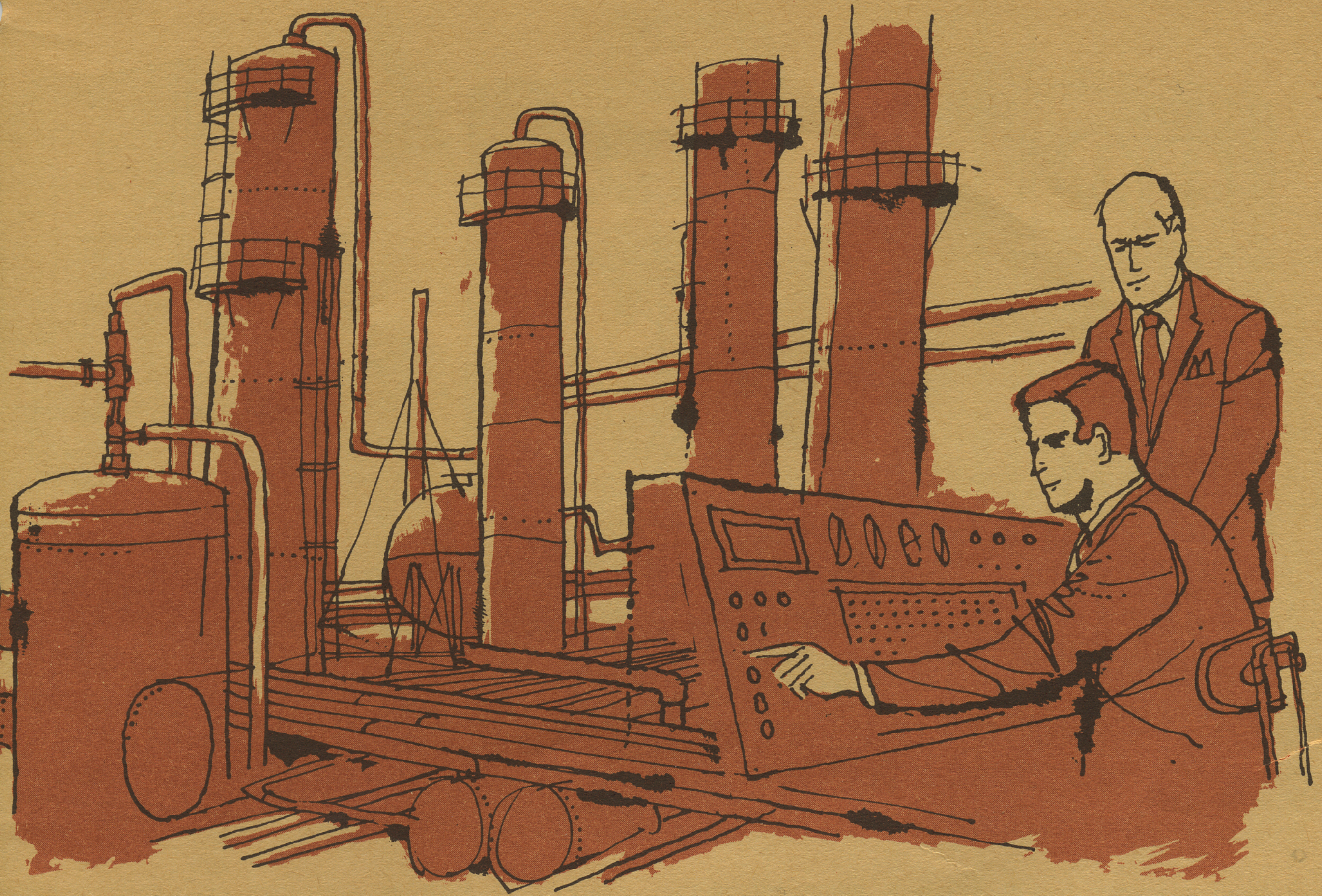
Once a program is ready, skilled operators record the instructions on punch cards or tapes. These are the computer's instructions and can be used over and over to solve that particular type of problem.

The programmer's task is not over when his program is translated into the specific machine code of the computer at his disposal. Nor is he finished once the machine has received the program. He must check it in operation, seek out errors, and correct them before accepting the answers. The understanding, ingenuity, and imagination needed in all phases of the work make programming a field for well-educated, intelligent men and women.

This description of the programmer's role reminds us that, regardless of name, computers are only *tools.* They are a means to increase the effectiveness of man's efforts. Like the sand counter, abacus, slide rule, and desk calculator, they need skillful hands and trained minds. Computers are mathematical steam shovels used by skillful operators to attack mountains of data. Edison said about genius: "It is 1 per cent inspiration and 99 per cent perspiration." Computers eliminate some of that perspiration, but they do not replace the inspiration. Only the human brain can create and control these tremendous tools.

In the nineteenth century, man invented many machines to employ energy for his benefit. He completely changed his methods of producing goods. We are now at the beginning of a second industrial revolution. Computers extend man's mental skills, just as machines and harnessed energy extend his physical power.

Although computers have many applications in modern life, the most familiar is for high-speed number calculations. How fast are they? One scientist expressed it this way: "They will add 8,000 numbers in the same time it took Wyatt Earp to draw his gun—one-fifth of a second." They're fast. But what is more important, they are extremely accurate. To make a working model from a rocket design requires millions of calculations and years of work. Computers complete the calculations in a few hours. To get our first earth satellite into orbit, scientists had to have solutions for the complex mathematical problems involved in firing successive rocket



stages within 200 seconds. Without electric computers, Explorer I would have been all but impossible.

The submarine simulator described at the beginning of this booklet is an example of another important application of computers. They are used to supplement conventional training devices by reproducing conditions more realistically. Let's see how computer simulators have affected flight training, for instance.

For many years there was only one way to test and train an airplane pilot, and that was to take him up in a plane. No one knew exactly how a man would react when he was alone. The solo flight was the only answer. About fifteen years ago, some pilot training was done with a dummy cockpit arrangement called a Link trainer. The cockpits were equipped with controls and aircraft instrument panels similar to those in real aircraft. The meters and dials of the panel were moved and changed by an operator outside the device. These devices gave some idea of the way men would react.

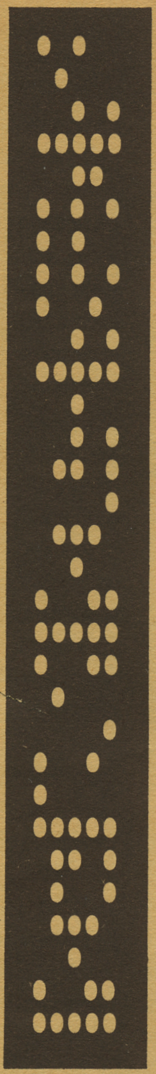
As useful as these were, they were limited because the readings in the cockpit did not instantly reflect the trainee's maneuvers. In the newer computer-trainers, greater realism is achieved. As the pilot moves the controls in response to his panel readings, the computer calculates the "plane's" response and changes the instrument readings on the panel accordingly. In addition, the pilot feels the kind of pull aircraft controls present in actual handling. Typical troubles and changes in air conditions can also be pre-set in the computer to add to the realism.

Devices of this type may seem like playthings, but their purposes are serious and important. Statistics show that costly training on actual aircraft can be reduced by 25 per cent with the computer trainer. Airmen can be safely trained and tested before they risk their lives and millions of dollars' worth of aircraft. New experimental planes can have "bugs" eliminated before the test pilot ever takes off.

Science, business, and industry use computers to help in making decisions. In deciding where to build service stations, an oil company can feed a computer all the factors involved in the decision, such as traffic flow, proximity to stores, and real estate costs. The machine will produce a decision or the alternate decisions most worthy of investigation.

One experiment with the decision-making ability of computers was a failure. A television quiz program used a computer to select the ideal wife for a contestant. When the two got to know each other, they decided they were mismatched. Whose fault was this? The machine operator's? Perhaps it only proves that even a computer cannot fathom a woman's mind!

NOW TRY THESE:



The tricks, problems, and experiments below will give you a better understanding of binary numbers.

1. Some devices receive information by means of punched paper tape. A code is used that shows each letter of the alphabet as a binary number. The binary number for each coded letter is recorded as a series of holes and spaces (no holes). Each hole stands for the symbol *one;* each space for a *zero.* For example, in one code the letter D, which is letter number *four* in the alphabet, would be shown as 1 0 0 in binary notation. It would be recorded as

Can you interpret the message?

2. Here's a mind-reading trick you can use on your friends. Make up four cards like this:

A	B	C	D
8 9 10 11 12 13 14 15	4 5 6 7 12 13 14 15	2 3 6 7 10 11 14 15	1 3 5 7 9 11 13 15

Hand your friend the cards and ask him to think of a number between 1 and 15. Now ask him to tell you the letters of the cards on which his number appears.

To do the trick, you must know this: Each card represents a column in a binary number. Card A is the 8's column, B the 4's, C the 2's, D the 1's. As the letters of the cards are called off, visualize a 1 in that column. If the card is not mentioned, visualize an 0. If he says his number is on A, B, and D, you should visualize:

A	B	C	D
1	1	0	1

This binary number represents 13.

If your friend were thinking of the number 8, he would call off A. You should visualize:

A	B	C	D	
1	0	0	0	= 8

If he were thinking of 15, he would call off A, B, C, D. You should visualize:

A	B	C	D	
1	1	1	1	= 15

3. Try extending the game above to include all numbers from 1 to 50. Can you do it? *Hint:* You'll need 6 cards to represent the six binary columns required for numbers that large.

4. Remember the hundreds of facts you needed to know when you learned addition and multiplication in the decimal system? In the binary system there are only four addition and four multiplication facts.

BINARY TABLES

ADDITION	MULTIPLICATION
1. $0 + 0 = 0$	1. $0 \times 0 = 0$
2. $0 + 1 = 1$	2. $0 \times 1 = 0$
3. $1 + 0 = 1$	3. $1 \times 0 = 0$
4. $1 + 1 = 10$	4. $1 \times 1 = 1$

Compare these examples in the decimal and binary systems:

ADDITION

$$\begin{array}{r} 9 \\ +\ 7 \\ \hline 16 \end{array} \qquad \begin{array}{r} 1\,0\,0\,1 \\ +\ \ 1\,1\,1 \\ \hline 1\,0\,0\,0\,0 \end{array}$$

DECIMAL / BINARY

MULTIPLICATION

$$\begin{array}{r} 9 \\ \times\ 3 \\ \hline 27 \end{array} \qquad \begin{array}{r} 1\,0\,0\,1 \\ \times\ 1\,1 \\ \hline 1\,0\,0\,1 \\ 1\,0\,0\,1\ \ \\ \hline 1\,1\,0\,1\,1 \end{array}$$

DECIMAL / BINARY

Try these problems in the binary system:
(a) $31 + 17$ (b) 12×19. Check your answers.

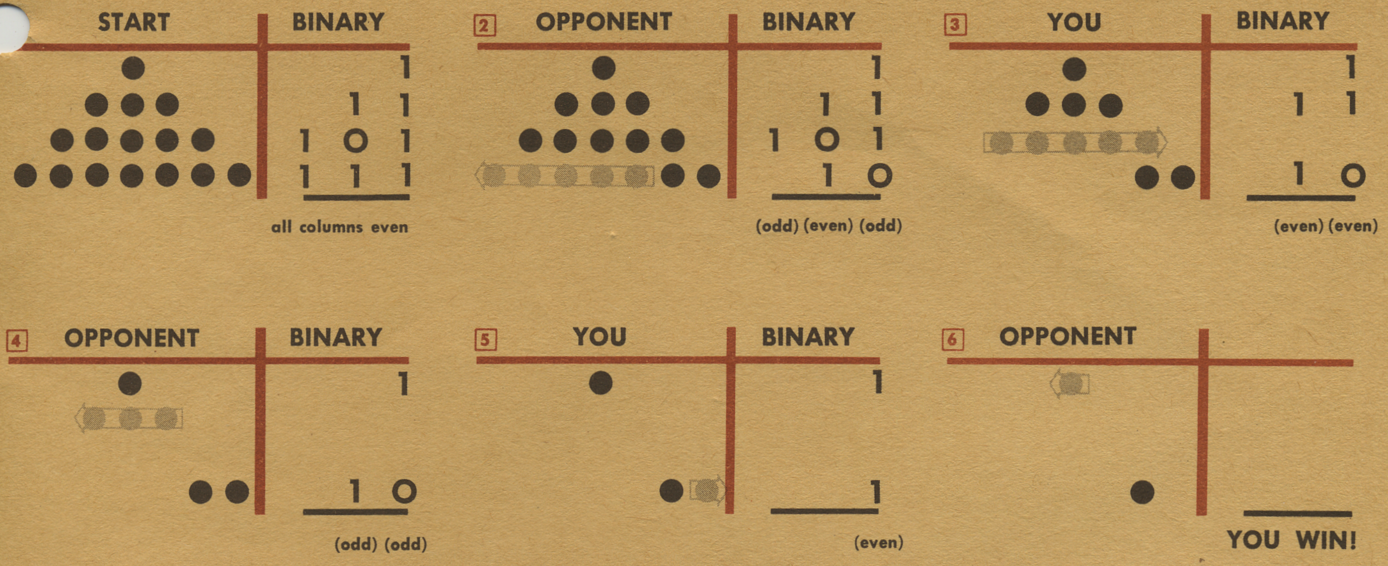
5. Develop a quinary number system using the number 5 as its base. (Use the symbols 0, 1, 2, 3, 4 to represent all numbers.) Write the numbers from 1 to 25 in this system.

6. Develop a duodecimal number system using twelve as a base. *Note:* You will need to create special symbols for ten and eleven. Why?

7. Here's one version of a very old mathematical game called NIM. Although the rules are simple, a knowledge of binary numbers is important if you are to be a consistent winner.

The game is played with sixteen coins arranged in four groups as shown at the top of the next page.

Two players are needed. They take turns in removing coins. During his turn, a player may remove any number of coins (from one to all) from any single group. The player who removes the last coin from the board wins the game.



The clue to winning is provided by the binary system. Express the number of coins in each group in binaries. This would be:

1	(1)
1 1	(3)
1 0 1	(5)
1 1 1	(7)

Notice that the number of 1's in each vertical column is even. The secret of the winning system is to choose your move so that the remaining number of coins, expressed in binaries, will always yield an even number of 1's in each binary column. (Other versions of NIM can be found on pages *101-108,* February, '58, issue of *Scientific American* magazine.)

READING LIST

If you want more information about number systems and computers, try some of the books listed below. Your librarian can help you find many others you will enjoy.

Makers of Mathematics. Hooper; Random House, 1948.

Mathematics in Western Culture. Kline; Oxford University Press, 1953.

The World of Mathematics (4 vols.). Newman; Simon and Schuster, 1956.

The Wonderful World of Mathematics. Hogben; Garden City Books, 1955.

Number Stories of Long Ago. Smith; The National Council of Teachers of Mathematics, 1955.

Numbers and Numerals. Smith and Ginsburg; The National Council of Teachers of Mathematics, 1951.

Number, the Language of Science. Dantzig; The Macmillan Co., 1945.

I Am a Mathematician. Wiener; Doubleday & Co., Inc., 1956.

Magic House of Numbers. Adler; The New American Library, 1957.

Mathemagic. Heath; Dover Publications, 1953.

Mathematical Puzzles. Mott-Smith; Dover Publications, 1954.

Fantasia Mathematica. Fadiman; Simon & Schuster, 1958.

Recreational Mathematics. Schaaf; The National Council of Teachers of Mathematics, 1955.

Fun With Mathematics. Meyer; World Publishing Co., 1952.

Giant Brains or Machines That Think. Berkeley; John Wiley & Sons, 1949.

The Electronic Brain and What It Can Do. Gorn and Manheimer; Science Research Associates, 1956.

Scientific American Magazine

Popular Electronics Magazine

COMPUTER KITS

Geniac Computer Kit. Oliver Garfield Co., 108 East 16 Street, New York 3, New York.

Brainiac. Berkeley Enterprises, Inc., 815 Washington Street, R 133, Newtonville 60, Mass.

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